Primary results of new gravity station Shaki/Azerbaijan

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Abstract

In this paper we discuss the first results of a gravity tidal record obtained with the new gravity meter manufactured by the company ZLS (Zero-Length-Spring Corp.). This is also the first record of this kind in a station in Azerbaijan. And we discuss the results with regard to the dynamics of the Earth-Moon system and the deformation of the Earth caused by tidal forces and regional contemporary movements and deformations.

The gravimeter is installed in the geodynamic station Shaki, Azerbaijan, operated by the Institute of Geology of the National Academy of Sciences of Azerbaijan. The data covers the period of 2010-2011 and was processed in the Institute of Geosciences, Friedrich-Schiller-University of Jena, Germany.

1. Introduction

The experimental data are important in the modelling of the tidal deformation to calculate the tidal corrections for high-precision measurements of gravity which, together with other high-precision geophysical measurements, will reflect the variable deformations and stress in the crust.

Strain is actively manifested at the boundaries of tectonic plates, in zones of contact platforms and seismic areas, in zones of deep faults of the crust. Information about long-term changes in displacement, gravity, deformation and tilt allows the evaluation of stresses in the Earth's crust to study the structure of the region and the connection with seismic activity (Balenko et al.1985; Pariyskiy et al. 1980; Hinderer & Crossley, 2000; Mantovani et al. 2005).

Observation of Earth tides is a promising method for geodynamic studies. Observation of different tidal components (tidal variations of gravity, tilt, linear and volumetric strains, ocean tides, etc.) make it possible to determine the amplitude- and phase-frequency characteristics of the different layers of the Earth, giving information on their viscoelastic properties in the range of nearly diurnal frequencies, and complement, thus, seismic results.

The highest accuracy is achieved in observations of tidal variations of gravity, but, compared to tilt and strain, they are less affected by anomalies in the crust and upper mantle.

Azerbaijan's territory is located in a zone of active collision of two continents, Africa and Eurasia (Mckenzie, 1972; Sengor et al., 1985; Philip et al., 1989; Kadirov et al., 2008).

Azerbaijan is part of the Alpine-Himalayan fold - erogenous zone. The main geomorphologic elements are the Large and the Lesser Caucasus, Talysh, Kura and South Caspian Basin. The modern structure of the region continues to be influenced by the opposing horizontal tectonic movements in the Arabian and Eurasian plates (Philip et al., 1989; Shevchenko et al., 1999; Khain, 2001; Jackson et al., 1992, Kadirov et al., 2008, and Ahmedbeyli, 2004).

Since Azerbaijan is located north of the north eastern (NE) corner of the Arabian plate, the horizontal movements of the plates cause strong deformations of the crust. Therefore, the territory of Azerbaijan is an inherent uneven location of seismic events.

Fig. 1 shows a map of GPS-derived site velocities within the territory of Azerbaijan in the context of selected GPS velocities in surrounding areas. Velocities are shown in an Eurasia-fixed reference frame determined by minimizing motions for GPS stations that have been observed well and are broadly distributed across the Eurasian plate.

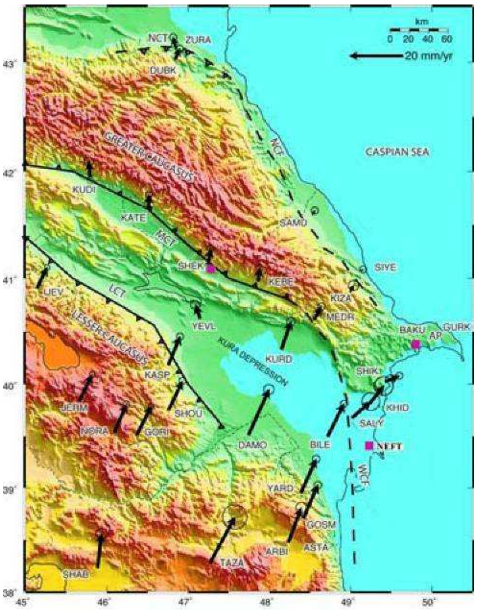

Figure 1. Azerbaijan GPS-Geodynamics Network. Triangles are survey sites and the square, the continuously recording GPS station at the Geology Institute, Baku. Base map shows topography, simplified tectonics. Abbreviations: NCT = North Caucasus Thrust fault, MCT = Main Caucasus Thrust fault, LCT = Lesser Caucasus Thrust fault, WCF = West Caspian Fault, NCF = North Caspian fault, AP = Absheron Peninsula (compiled by F. Kadirov, S. Mammadov, R. Reilinger, S. McClusky).

Velocity uncertainties are mostly less than 0.6 mm/yr, allowing fairly precise estimates of convergence across the Caucasus mountain system (i.e., uncertainties are about 5% of the total convergence rate; Kadirov at al., 2009; Reylinger at al., 2008). On a broad scale, the GPS velocity field clearly illustrates the NNE motion of Azerbaijan and adjacent regions of the Lesser Caucasus with respect to Eurasia south of the MCT. The most pronounced feature of the velocity field is the decrease in site velocities across the MCT.

2. Shaki station

Shaki station of the Institute of Geology of Azerbaijan National Academy of Sciences is located on the north-west of Azerbaijan (Fig. 2). In the foothills of the Greater Caucasus at a height of 723 m, and is the main Earth-tidal station in Azerbaijan. The station is located on the territory of Shaki Research Centre. Construction of the plant began in 2009. It consists of a separate room of 3m x 4m. In the middle of the room there is a concrete pillar of a size of 80cm x 80cm and a depth of 1.5 meters with a height above the ground of 65cm (Fig. 3).

The coordinates of the station are: 41.2220°N, 47.1710°E, elevation: 723.000 m.

Tidal measurements at the station Shaki began in March 2010. Excluding breaks in recording, the observations cover 358 days in a time span of little more than one year (01.04.2010 until 08.04.2011). We installed the automated Burris Gravity Meter B-14 (Adams et al., 2004; Jentzsch, 2008).

The Burris Gravity Meter™ is a product of the company ZLS Corporation, Austin/Texas, USA. It is based on the invention of L. LaCoste and A. Romberg (LaCoste, 1942): The zero length spring (ZLS).

Figure 2. Azerbaijan gravity station Shaki.

Figure 3. Azerbaijan gravity station Shaki.

The high-precision automated Burris gravimeter ensures accuracy in stationary observations to 0.1 microgal. The sensor type is a metal zero-length spring supported by a hardened metal micrometer screw with a range of 7,000 mGal. The feedback range is about ± 25 mGal, but can be reduced for Earth tidal purposes[1].

Particular attention was paid to ensure the temperature stability of the room. The temperature is kept constant throughout the year at around 2 to 3°C. In the winter and summer months, especially when large temperature differences occur, the gravimeter was covered by a special insulation.

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[1] This gravimeter is mostly used for surveying and has demonstrated its superb quality (Ziang et al., 2012), some groups have provided continuous records (Poland & Carbone, 2010), using a WINDOWS based recording system now available which includes a digital barometer and a GPS time control. The data are stored on the hard disk of a notebook computer (www.gravity-consult.de).

3. Data analyses

Data processing and analysis was carried out in the Institute of Geosciences, Friedrich-Schiller-University of Jena, Germany. The observation results were processed using a combination of programs PreAnalyse (Gebauer et al., 2007) and ETERNA (Wenzel, 1996).

- Data acquisition system: For recording the data we used the program UltraGrav™ provided by ZLS with the control-computer HP200 palm-top. The HP200 employs the familiar DOS operating system. Data are stored on a PC memory card. This PC memory card is used like a floppy disk to transfer data from the HP200 to a host computer equipped with a PC memory card interface[2].
- Dynamic of recording: For long-term Earth tide (ET) observations and secular studies we are using the function “Continuous observations”. This function permits the continuous measurement of gravity as required for Earth tide observations and secular gravity studies.
- Sample rate: The date sample rate was set to 3 minutes.
- Time base: Date and time were adjusted to UTC.
- Interpolation of gaps: During the primary treatment we introduced gaps where data were missing.
- Filtering: The 3min samples were interpolated to 1 Min., cleaned with PreAnalyse and filtered to 5min- and 1-hour-samples.
- Gaps in the data are associated with power failures.

As a result of the treatment a time series of hourly values was obtained (Fig. 4). A linear drift, superimposed by a seasonal period is clearly shown, in which the tidal amplitude is changing from about -100 nm/s^2 (10 µGal) to approx. -2000 nm/s^2 (-200 µGal). This drift rate is typical for spring gravimeters, even if they are specially constructed for the observation of Earth tides (Hegewald et al., 2011). Fortunately, there was only one bigger gap in the time series at the beginning of December 2010, due to power failure.

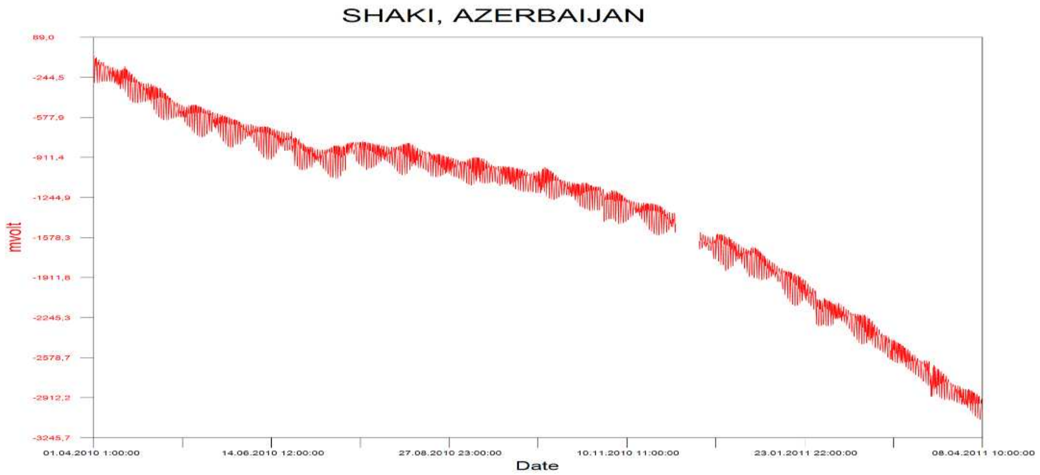

Figure 4. Tidal observation at station Shaki hourly values (calibration factor 1mvolt = 12.88 nm/s^2)

We have computed the amplitude and phase spectrum of the hourly time series (Fig. 5: amplitude in nm/s^2; phase in degrees, Fig. 6). The result shows clearly the diurnal and semi-diurnal tidal wave groups (Fig. 5). The long- and aperiodic drift behaviour shown in Fig. 4 can be seen in the lower frequencies of the spectrum, where the values rise up to some hundreds nm/s^2.

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[2] See footnote 1.

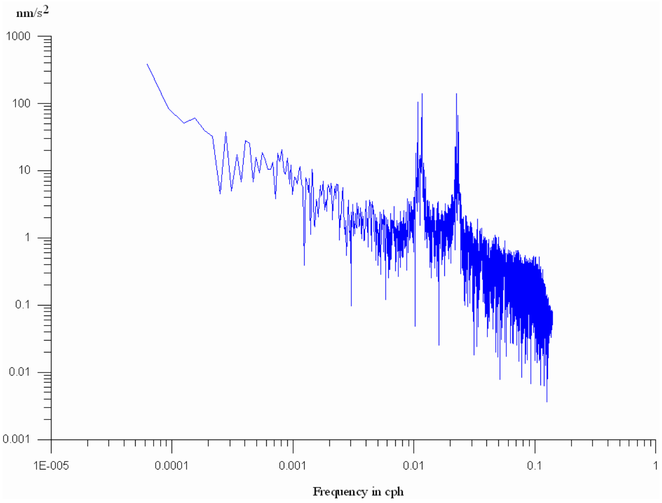

Figure 5. Amplitude spectrum in nm\s^2

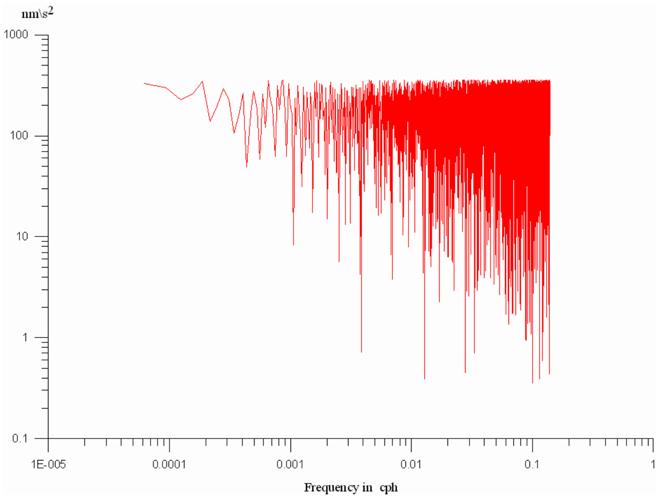

Figure 6. Phase spectrum in degrees.

4. Results – tidal parameters

The time series were analyzed using the tidal analysis program ETERNA3.4 (comp. Wenzel, 1997), and 18 main tidal constituents are used. Unfortunately, the barometric pressure could not be taken into account, because no parallel recording could be provided. The results with a standard deviation of 2.3nm/s² show the expected tidal parameters for an elastic Earth with a tidal factor of about 1.16 and phase differences close to zero for what concerns the main tidal constituents O1 and M2. The ocean tides loading is certainly not very large. S2 is clearly affected by the atmospheric pressure effects. The amplitude factor of M3 is close to the theoretical value 1.07 for the ter-diurnal waves. Only the tidal waves with very small amplitudes like J1, OO1 and also M4 show large errors or phase differences (Table 1).

The good quality of the tidal analysis is also confirmed by the tidal residuals (Fig. 8). The residuals mainly consist of white noise, however a seasonal variation can be seen. In autumn and winter time, at the end and at the beginning of the time series higher residuals of up to ± 10nm/s² are observed, whereas in summer time (mid of time series) the amplitudes vary by about ± 5nm/s² only. This is probably caused by the effect of barometric pressure variations, which usually show higher amplitudes in winter than in summer time.

Table 1. Adjusted tidal parameters estimated by the tidal analysis (ETERNA3.4).

From [cpd]	To [cpd]	wave	amplitude nm/s^2	amplitude factor	Standard deviation	phase lead [deg]	Standard deviation [deg]
0.501370	0.911390	Q1	66.94	1.135	0.008	1.84	0.43
0.911391	0.947991	O1	354.57	1.151	0.002	0.96	0.08
0.947992	0.981854	M1	28.23	1.166	0.016	-0.41	0.78
0.981855	0.998631	P1	161.07	1.124	0.004	-0.55	0.19
0.998632	1.001369	S1	17.58	5.194	0.229	77.60	2.53
1.001370	1.004107	K1	489.74	1.131	0.001	1.18	0.06
1.004108	1.006845	PSI1	10.76	3.176	0.155	-8.09	2.80
1.006846	1.023622	PHI1	8.77	1.422	0.087	20.12	3.50
1.0236230	1.057485	J1	26.88	1.110	0.021	7.41	1.11
1.057486	1.470243	OO1	15.09	1.139	0.030	5.25	1.51
1.470244	1.880264	2N2	15.61	1.201	0.031	8.62	1.47
1.880265	1.914128	N2	95.78	1.177	0.006	1.83	0.31
1.914129	1.950419	M2	498.03	1.171	0.001	1.30	0.06
1.950420	1.984282	L2	13.90	1.157	0.051	-6.19	2.55
1.984283	2.002736	S2	229.43	1.160	0.003	0.61	0.13
2.002737	2.451943	K2	60.62	1.128	0.009	2.81	0.47
2.451944	3.381478	M3	6.79	1.079	0.077	1.08	4.10
3.381379	4.347615	M4	0.63	7.322	5.476	57.38	42.85

The tidal analysis also shows the well known *Nearly Diurnal Free Wobble* (NDFW) of the Earth, which is caused by the forced oscillation of the Earth core (Zürn, 1997). If the quality of the gravity time series is high enough this geodynamic effect can be detected in the diurnal frequency band: The tidal parameters of small constituents of PHI1 and PS1 should be higher than 1.16 and for the main constituent K1 should be slightly reduced compared to O1. Fig. 9 shows these parameters over the time in hours, and it is obvious that the NDFW was significantly observed by the gravity record in Shaki-station.

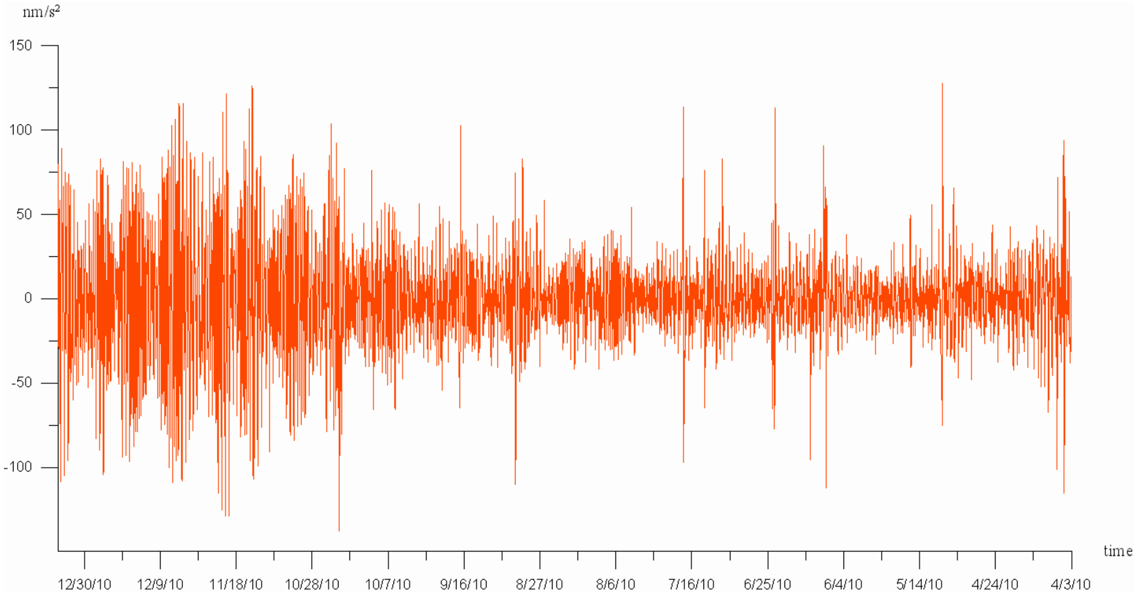

Figure 8. Tidal residuals after tidal analysis (ETERNA3.4).

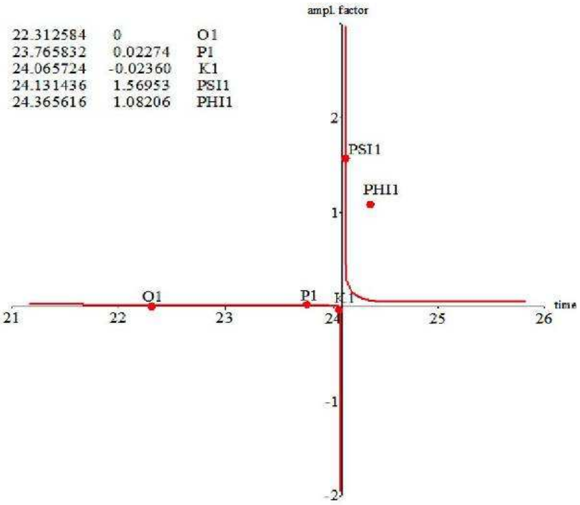

Figure 9. Nearly diurnal free wobble, caused by the Earth core is clearly indicated by the gravity observation in Shaki station.

5. Results – monthly analyses

The record was analyzed piecewise using moving windows of three months length each, moved by one month. Thus, the results were allocated to the middle centre month of the intervals. Tables 2 and 3 give the obtained results for amplitude factor and phase lead; Figures 9 and 10 give the plots of these results. Applying the errors obtained, in the semidiurnal tidal band the variations are not significant, whereas in the diurnal tidal band in some cases the error bars do not overlap. Especially in the case of the phase it seems to be strange, that all results show decreasing phases towards the end of the recording period. The fact the phase shift of M2 is nearly twice the phase shift of O1 points obviously to a timing error due to the drift of the clock.

Table 2. Amplitude factor: Monthly results for the main tidal waves O1, P1S1K1, M2, and S2, estimated by tidal analysis (ETERNA3.4).

Date	O1	P1S1K1	M2	S2
May	1.146 ± 0.005	1.138 ± 0.003	1.168 ± 0.002	1.163 ± 0.005
June	1.148 ± 0.005	1.129 ± 0.003	1.168 ± 0.002	1.157 ± 0.004
July	1.147 ± 0.005	1.116 ± 0.003	1.168 ± 0.001	1.173 ± 0.004
August	1.158 ± 0.004	1.114 ± 0.003	1.169 ± 0.002	1.165 ± 0.004
September	1.151 ± 0.003	1.102 ± 0.003	1.171 0.0014	1.178 ± 0.005
October	1.154 ± 0.003	1.117 ± 0.002	1.172 ± 0.001	1.181 ± 0.004
November	1.157 ± 0.004	1.116 ± 0.002	1.172 ± 0.004	1.168 ± 0.008
December	1.142 ± 0.005	1.122 ± 0.003	1.169 ± 0.003	1.199 ± 0.009

6. Conclusions

For the first time, a Burris gravimeter was used for tidal recording for a period of a little over one year. The results show that the gravimeter is stable and very well suited for such a purpose. Although the data quality is not as good as it could be due to the recording with a palm top, we are quite satisfied with the results. Compared to the environmental conditions the drift is quite tolerable and in accordance with other findings related to spring gravimeters. We hope to further improve the recording by replacing the palm top by a recording system with higher resolution, GPS time receiver and digital barometer to be provided by Gravity Consult GmbH.

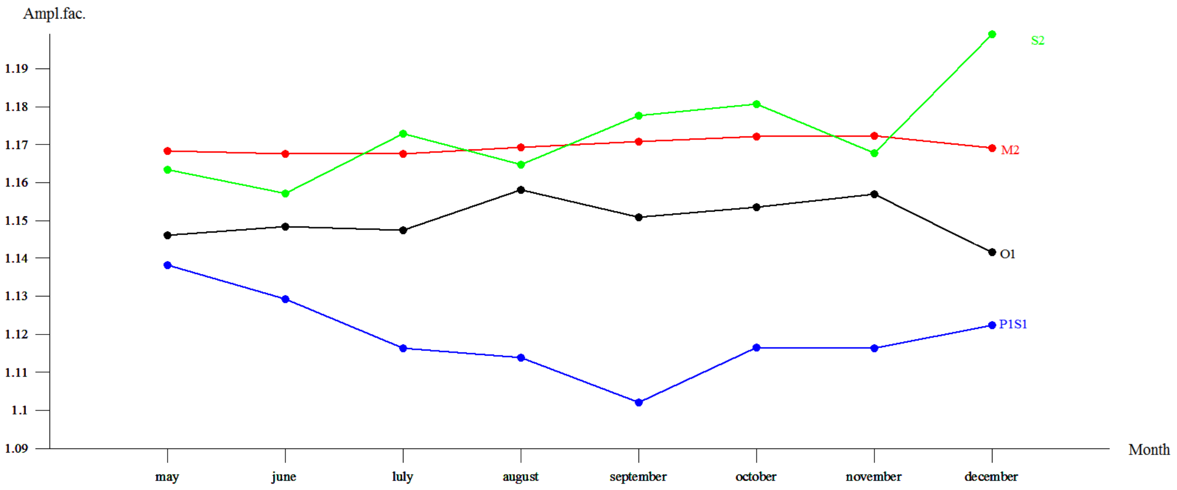

Figure 9. Amplitude factor: Monthly results for the main waves O1, P1S1K1, M2, and S2 estimated by tidal analysis (ETERNA3.4).

Table 3. Phase lead: Monthly results for the main waves O1, P1S1K1, M2, and S2 estimated by tidal analysis (ETERNA3.4).

Date	O1	P1S1K1	M2	S2
May	0.68 ± 0.25	0.56 ± 0.16	1.61 ± 0.09	0.77 ± 0.26
June	0.68 ± 0.25	0.52 ± 0.15	1.39 ± 0.08	-0.35 ± 0.22
July	0.73 ± 0.23	0.42 ± 0.15	0.84 ± 0.07	-0.12 ± 0.18
August	0.50 ± 0.21	0.18 ± 0.16	0.35 ± 0.09	-0.78 ± 0.21
September	0.08 ± 0.17	0.50 ± 0.15	-0.08 ± 0.07	-1.20 ± 0.22
October	-0.19 ± 0.15	1.39 ± 0.12	-0.59 ± 0.06	-2.40 ± 0.21
November	-0.65 ± 0.18	1.10 ± 0.12	-1.57 ± 0.13	-2.51 ± 0.38
December	-2.01 ± 0.24	-0.04 ± 0.14	-3.71 ± 0.14	-6.32 ± 0.42

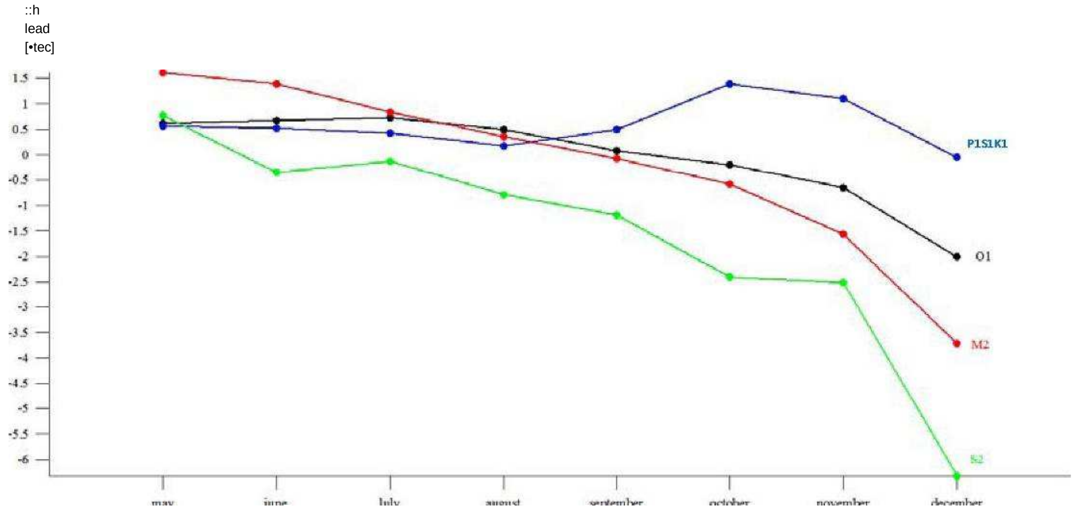

Figure 10. Phase lead: Monthly results for the main tidal waves O1, P1S1K1, M2, and S2 estimated by tidal analysis (ETERNA3.4).

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8. References

Adams, J., L. Burris, G. Jentzsch, A. Kopaev, and H. Valliant, 2004. The Automated Burris Gravity Meter - a New Instrument for Surveying and Continuous Operation. 15th Int. Symp. Earth Tides, Ottawa, August 2004, Abstract Book.

Ahmedbeyli F.S., Qasanov A.Q., Kadirov F.A., Kadyrov A.H., Rzayev A.Q., Yetirmishly Q.D., Mammadov S.K., Quseynova V.P., 2004. Distribution of earthquake epicenters and seismic energy released in the territory of Azerbaijan (tectonic aspects, and some patterns). Catalogue of earthquakes, of the Republican Center of Seismological service of Azerbaijan National Academy of Sciences, Baku, pp.137-150.

Balenko I.Q., Barsenkov S.N., Bulancev V.Q., Qrideev D.Q., Dichenko I.A., Saricheva Y.K., Timofeev V.Y., 1985. Tidal gravity measurements in Novosibirsk in 1977-1979. Slowly deformation of Earth and its rotation. Moscow journal Radio and communication, pp. 40-59.

Gebauer, A., T. Jahr, and G. Jentzsch, 2007. Recording and interpretation/analysis of tilt signals with five ASKANIA borehole tiltmeters at the KTB. Review of Scientific Instruments, Vol.78, No.5.

Hegewald, A., G. Jentzsch, and T. Jahr, 2011. Influence of temperature variations on the noise level of the data of the LaCoste & Romberg Earth Tide gravity meter ET18. G-cubed, Vol. 12, No. 4, 8 pp, doi:10.1029/2010GC003432.

Jiang Z., Рблinkбљ V., Francis O., Jousset P., Мдkinen J., Merlet S., Becker M., Coulomb A., Kessler-Schulz K., Schulz H., Rothleitner Ch., Tisserand L., Lequin D., 2012. Relative Gravity Measurement Campaign during the 8th International Comparison of Absolute Gravimeters (2009). Metrologia.

Jackson, J., 1992. Partitioning of strike-slip and convergent motion between Eurasia and Arabia in eastern Turkey. J. Geophys. Res., 97, pp. 12471-12479.

Jentzsch, G., 2008. The automated Burris gravity meter – a new instrument using an old principle. Proc. Symposium on Terrestrial Gravimetry: Static and Mobile Measurements, St. Petersburg, Russia, 20-23 Aug. 2007, pp. 21-28.

Hinderer, J. and Crossley, D., 2000. Time variations in gravity and inferences on the Earth's structure and dynamics, Surv. Geophys., 21, pp. 1-45.

Kadirov, F. Mammadov, S., Reylinger. R., McClusky, S., 2008. Some new data on modern tectonic deformation and active faulting in Azerbaijan (according to Global Positioning System measurements). J. Proceeding the Sciences of Earth, Azerbaijan National Academy of Sciences, №1, pp. 83-88.

Kadirov F.A., Kadirov A.H., Aliye F.A., Mammadov S.K.,Safarov R.T., 2009. Correlation between speeds of horizontal movements defined on GPS to measurements in Azerbaijan and seismicity of the Create Caucasus. Catalogue of the seismoforecasting research carried out of Azerbaijan territory in 2008. Republican Survey Seismic Center of Azerbaijan National Academy of Sciences, pp. 121-126.

Khain V.E., 2001. Tectonics of continents and oceans, Moscow, Book, The scientific world, 606 pp.

LaCoste, 1942. US Patent 2293437. Cited after: Larson, J.V., (1968), A cross correlation study of the noise performance of electrostatically controlled LaCoste and Romberg gravimeters. Technical Report No. 752, University of Maryland, Dept. of Physics and Astronomy, College Park, Maryland.

Mantovani, M.S.M., Shukowsky, W., de Freitas, S.R.C., Brito Neves, B.B., 2005. Lithosphere mechanical behaviour inferred from tidal gravity anomalies: a comparison of Africa and South America. Earth Planet Sci. Lett. 230, pp. 397-412.

McKenzie, D.P., 1972. Active tectonics of the Mediterranean region, Geophys. J. R. Astron. Soc., 30, pp. 239-243.

Pariyskiy, N.P., Barsenkov, S.N., Volkov, V.F., Qridnev, D.Q., Kuyznetsov, L.V., Percev, B.P., Saricheva, Y.K., Varqa, P., Shimon, E., 1980. Tidal gravity variation in the USSR. Study of earth tides, Moscow. Science, pp. 65-84.

Philip, H., A. Cisternas, A. Gvisiani, and A. Gorshkov, 1989. The Caucasus: An actual example of the initial stages of continental collision, Tectonophysics, 161, pp. 1-21.

Poland, M.P., and D. Carbone, 2010. First results from continuous gravity measurements at Kilauea Volcano, Hawai'i. Poster G23C-0833, AGU Fall Meeting, San Francisco, December 2010.

Sengor, A.M.C., N. Gorur, and F. Saroglu, 1985. Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In: Biddle, K.T. and N. Christie-Beck, (eds.) Strike-slip Faulting and Basin Formation, Society of Econ. Paleont. Min. Sec. Pub., 37, pp. 227-264.

Shevchenko, V.I., Quseva, T.V., Lukk, A.A. et al., 1999. Modern geodynamics of Caucasus by results of GPS measurements and seismological data. J. Physics of the Earth, №9, Moscow, pp.3-18.

Wenzel, H.-G., 1996. The nanogal software: Earth tide data processing package ETERNA 3.30. Bull. D'Inf. Marйes Terr., 124, pp. 9425 – 9439.

Zürn, W., 1997. The nearly diurnal free wobble-resonance. In: Wilhelm, H., W. Zьrn, and H.-G. Wenzel (Eds.), 1997. Tidal Phenomena. Lecturer Notes in Earth Sciences, 66, pp. 95 – 109.